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LEAD GLASS TOTAL ABSORPTION COUNTERS

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Contents

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The Cerenkov counter cells and their supporting stands were designed by Bruce H. Rule and Dan Sell. B. T. Ulrich, D. Carmichael, and G. Greenstein were helpful in testing phototubes and building some of the electronics. The recent modifications were made by Richard M. Talman.

I Introduction

Two identical large lead glass shower detectors[1], or Cerenkov counters, have been built to detect and measure the energies of decay photons from neutral pions. This method of detecting high energy gamma rays has the advantage of 100 per cent efficiency, good energy resolution, linearity of response, insensitivity to heavy charged particles, and short time resolution. In addition, the physical size of the detector need only increase logarithmically with the energy of the incident particle to preserve linearity and resolution.

II Principle of Operation

A high-energy gamma ray or an electron incident on the glass will initiate an electron-photon shower. If the volume is large enough so that a small fraction of the shower escapes from the glass, the primary mechanism for energy loss is ionization due to the electrons. If we assume that both the ionization loss and the Cerenkov light emitted per unit path length are independent of the electron energy, then the amount of light emitted is proportional to the total energy of the incident particle. There are three main sources of fluctuations in the output pulse heights: fluctuations in the energy lost in the glass, fluctuations in the direction of the shower, and the statistics of electron emission at the photocathode. For these counters, the last seems to be the primary source of the width of the response.

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[1] A summary of early work on the subject may be found in R. Hofstadter, CERN 59-4 (unpublished).

III Construction of Counters

The total absorption gamma-ray spectrometers are made of type DF-4 lead glass supplied by the Hayward Scientific Glass Corporation. The properties of this glass are summarized in Table 1. Each counter consists of two 14" x 14" x 6" glass blocks polished on all surfaces and set on top of each other with a .002" layer of 1-Bromonapthalene between them as a matching liquid. Cerenkov light produced inside the glass is detected by nine 5" photomultipliers (RCA type 7046) optically coupled by a thin layer of Celvacene vacuum grease to the surface of the glass opposite to where the particles enter. The other five faces are wrapped in aluminum foil to increase light collection efficiency. For shielding from stray magnetic fields, the individual phototubes are wrapped with layers of conetic and fernetic foil and the whole assembly is encased in a 1/4" mild steel box. The front face of this cell has a 4" x 7" aperture* covered by a 1/16" aluminum plate. Details of the counter assembly are shown in Fig. 1.

The phototubes used on the Cerenkov counters were selected for gain and relative photocathode efficiency. The high voltages were individually adjusted so that the output pulse height was the same for all the tubes with the same number of incident photons. The timing of the signals into a nine-channel mixer was adjusted by the length of cable from the tube bases. The rise time of the output signal is ~ 5 nsec.

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* Recently increased to approximately 10" x 9".

TABLE 1

Summary of Lead Glass Characteristics

Glass Type DF-4 Code 649-339

Density 3.88 gm/cm^3

Index of refraction $n_D = 1.649$ Dispersion $n_F - n_C = .019$

Radiation length 2.5 cm

Energy loss for a 500-Mev electron 4.5 Mev/cm

Composition	K_2O	6 per cent
	SiO_2	41 per cent
	PbO	52 per cent

Manufactured by Hayward Scientific Glass Corporation, Whittier, California

IV Calculation of Response

The fluctuations in energy lost from the glass can be calculated assuming that the energy leaves in the form of photons at the minimum of the absorption curve. Reference 1 gives a discussion of this technique. For these counters, only a few per cent of the energy of a 1-Gev shower is lost. This would lead to negligible spread in the response.

The number of photoelectrons expected for a given incident energy can be estimated from folding together the spectrum of Cerenkov light, the absorption in the glass, and the spectral response of the photocathode. The absorption spectrum of the glass was measured on a four-inch sample on a Cary Recording Spectrophotometer. To estimate the path length of the light in the glass, we assume all the light comes from the peak of the shower four radiation lengths in from the front surface.[2)] Thus there are ten inches of absorption length. The number of photons per centimeter of path radiated by Cerenkov light in a wave length interval $d\lambda$ is[3)]

$$\frac{dN}{dX} = 2\pi\alpha \left(\frac{n^2-1}{n^2}\right) \frac{d\lambda}{\lambda^2} \tag{1}$$

where $n = n(\lambda)$ is the index of refraction. Figure 2 shows the absorption, Cerenkov, and S-11 response spectra used in calculating the number of photoelectrons.

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2) R. R. Wilson, Phys. Rev. 86, 261 (1952).

3) W.K.H. Panofsky and M. Phillips, "Classical Electricity and Magnetism", Addison-Wesley (1955).

A 1-Gev shower trapped in the glass will, assuming an ionization loss of 4.5 Mev/cm independent of energy, radiate over 220 cm of path length. For a 10 per cent photocathode efficiency and a 100 per cent light collection efficiency, we should see 3800 photoelectrons. The actual light collection efficiency will probably be much lower for several reasons. First, the phototubes cover only 63 per cent of the rear face of glass or about 10 per cent of all the glass. Secondly, measurements indicate that the light is distributed nearly isotropically, which may be due to spread in the shower and to multiple reflections in the glass. Also, because of the strong absorption in the ultraviolet, the shorter wavelengths which predominate in the Cerenkov light may be strongly scattered. These last two points also argue for taking into account that the typical length for absorption is probably longer than the ten inches assumed. As discussed in the next section, the number of photoelectrons from a 1-Gev shower appears to be 270.

V Performance of the Counters

Measurements were made on the counters using a momentum selected electron beam. The beam was defined by a collimator in the bremsstrahlung beam, a slit system in a uniform field magnet, and two narrow plastic scintillators in front of the counter. The momentum resolution of the system was $\Delta p/p = \sim .03$. The momentum calibration was done by lowering the end point of the bremsstrahlung spectrum until the counting rate went to zero.

The output pulses from the phototubes on the glass block were added in a nine-channel mixer, amplified by two Hewlett-Packard distributed amplifiers, and passed through a 50 nsec gate opened by a fast coincidence between the two scintillators. The output of the gate was stretched, amplified, and displayed on a twenty-channel pulse-height analyzer. Pulse heights in the system were kept constant by adjusting an attenuator placed just after the mixer.

Response curves for the Cerenkov counters are shown in Fig. 3. The linearity and width of the response are plotted in Fig. 4. The pulse height spectrum after subtracting a low energy tail is fitted with a Gaussian distribution to get the width, σ. The fact that the width vs. $1/\sqrt{I}$ curve is linear and has a small intercept at infinite energy shows that the width of the response is mainly due to statistics in photoelectron emission. The width vs. energy relation is approximately

$$\sigma = 61 \text{ Mev} \sqrt{E/1 \text{ Gev}} \ . \tag{2}$$

This width corresponds to 270 photoelectrons at 1 Gev. A secondary calibration using cosmic-ray muons defined by scintillation counters above and below the Cerenkov gives at the peak of the spectrum pulse height equivalent to a 201-Mev electron (Fig. 3).

The number of photoelectrons can also be calculated from the pulse height if the phototubes have been calibrated. This was done for the center tube using a light pulser and calculating the number of photoelectrons from the width of the response at low light intensities. Because of the manner in which the tube gains were set, and the fact that the center tube was above average in photocathode efficiency, this procedure gives an overestimate of the number of photoelectrons. The number measured was 350 photoelectrons which was considered reasonable agreement.

We have investigated the distribution of light intensity on the surfaces of the glass block. As was described above, the phototube gains were set so that the ratio between output pulse height and average light intensity on the photocathode is the same for all phototubes. The intensity distributions for different counter arrangements are shown in Fig. 5. With the blocks rotated so that the plane of the photocathodes are parallel to the incident electron beam, we get out 94 per cent as much of the light as with the plane perpendicular. Blackening the side opposite the one through which the electrons enter reduces the output by another 10 per cent. The output is reduced only 6 per cent when the electrons enter two inches from the edge of the glass. With the blocks aluminized, we get 64 per cent of the light, indicating that there are many reflections. It would appear from the near isotropy of the light that shower has spread greatly in angle or that there is large scattering of the ultraviolet.[4)]

VI Experience with the Counters

During the past two years of operation, several important observations have been made about the utilization of the counters. The gain is

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4) A recently built counter at CERN with similar dimensions has been found to be linear within 3 per cent up to 14 Gev. The explanation given is that the effects of energy lost from the glass and the shower maximum moving closer to the phototubes tend to cancel. At 14 Gev, the spectrum shows a long low energy tail and a full width at half maximum of 7 per cent. See Gatti et al., Rev. Sci. Inst. 32, 949 (1961).

very sensitive to variations in the phototube high voltage and to the presence of nearby magnets. It is recommended that frequent cosmic-ray calibrations be taken to check for gain drifts. Recently, a small neon light source has been mounted in each counter which may be pulsed to use for calibrating the gains over a short time interval.

The two counters have been used in coincidence down to 10 nsec with pulse heights varying over a 6 : 1 range. If the counters are used in close proximity, care must be taken to eliminate spurious coincidences due to cosmic-ray events passing through both of them. The counters are also sensitive to charged pions which may produce neutral pions through charge exchange or nuclear stars giving large pulses. The response of the counters to pions has not been measured, but this effect should be taken into account in designing shielding for the counters.

The counters were taken apart after over a year of continuous operation and it was found that all of the Celvacene joints and the matching layers were still in good condition. At this time, the apertures were enlarged to approximately 10" high x 9" wide. The phototubes were recalibrated and the counters put together again. Repeating the measurements in an electron beam gave substantially the same results for the resolution.

If better energy resolution is needed, it is possible to redesign the cells so that phototubes could be mounted on the top and side faces of the glass. This would, however, make the assembly much bulkier and more difficult to shield against stray magnetic fields and radiation.

APPENDIX

Further Measurements on Light Output

The problem of low light output was investigated further on two additional samples of the same type of glass: a cube about 1.4" on a side and a long block 1.4" square by 12" long. Tests were run with and without aluminum foil wrapping using cosmic-ray muons. The blocks were viewed by an RCA 6810 phototube which had been calibrated directly in photoelectrons using a light pulser.

The runs with the small cube are summarized in Table 2. The 110 photoelectrons in the best case (phototube vertical, block wrapped in aluminum) is in good agreement with the number calculated by the method described in the text. The much broader width than would be expected from the photoelectron statistics is due to the large variation in path length for the muons.

The long block was used primarily as a check on the absorption. The glass was held with the long axis horizontal and the phototube on one end. The position of the scintillators above and below the block which defined where the muons entered could be moved to different positions along its length. Except for a sharp rise very close to the end nearest the phototube due to an increase in solid angle, the pulse height showed no variation with distance, implying that absorption and scattering were not important effects. The pulses out of the long block were about half as large as from the cube in the same configuration.

The measurements on the smaller blocks do not shed much light on the resolution of the Cerenkov counters as in the smaller blocks the effects seem primarily geometrical. In the large counters with the possibility of multiple reflections, the effects of absorption and scattering should be more important. The results on the small blocks show that it may be possible to construct a large counter of many long pieces of glass to get better energy resolution.

TABLE 2

Measurements on Small Glass Block

Phototube Position	Wrapping	Number of Photoelectrons From Pulse Height	From Width
Horizontal	None	55	
Vertical	None	92	
Horizontal	Aluminum	63	15
Vertical	Aluminum	110	21
Vertical	Five Sides Blackened	71	

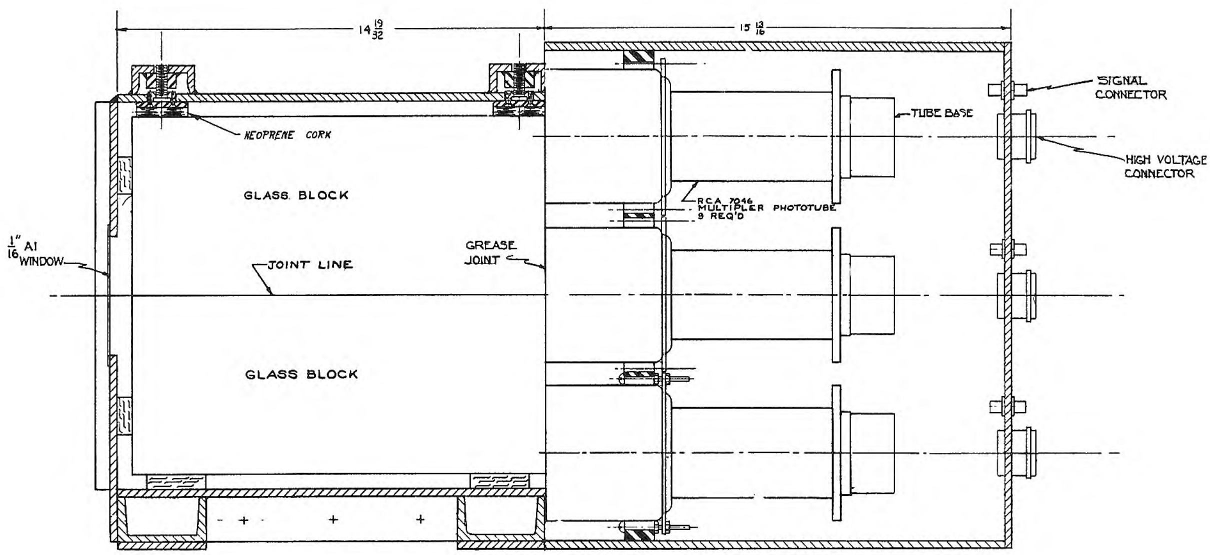


FIGURE 1: Cerenkov counter assembly showing details of construction and phototube mounting.

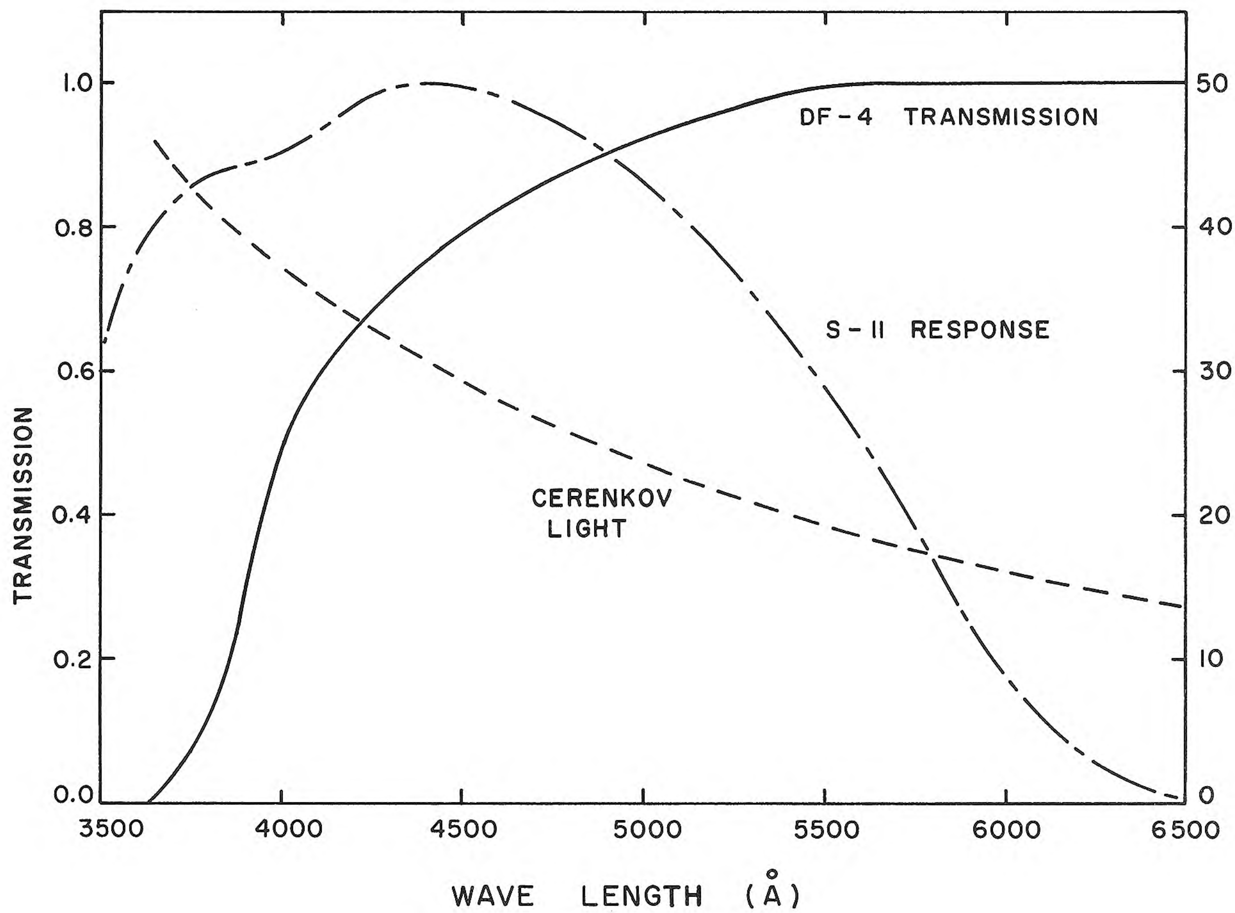
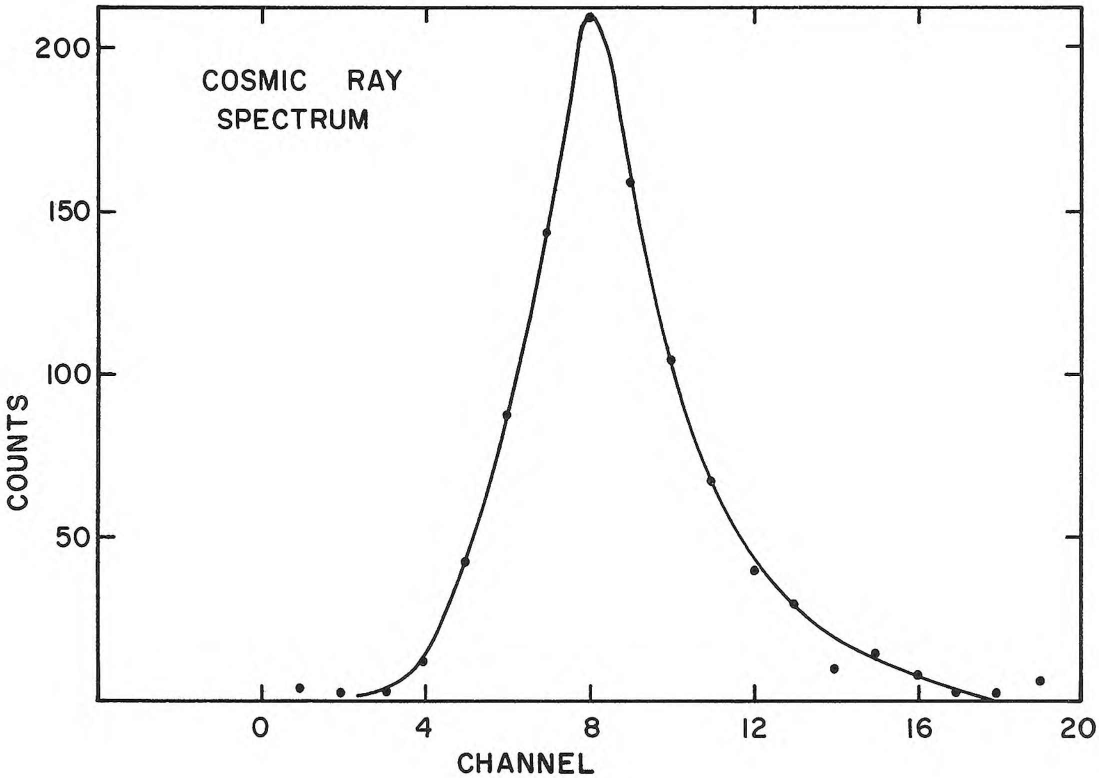


FIGURE 2: **The spectrum of Cerenkov light, absorption in ten radiation lengths of glass, and the S-11 response curve for the phototubes.**



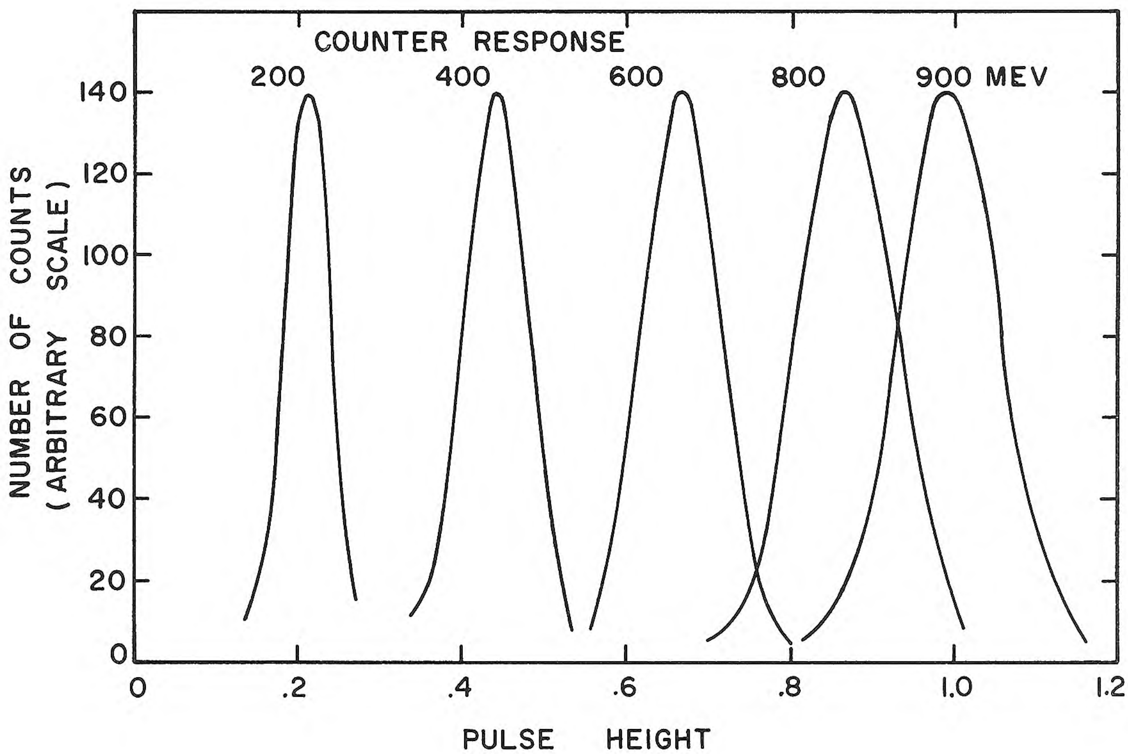


FIGURE 3: Response of the Cerenkov counters to monoenergetic electrons and to cosmic ray muons used for calibration. The energy scale is approximate.

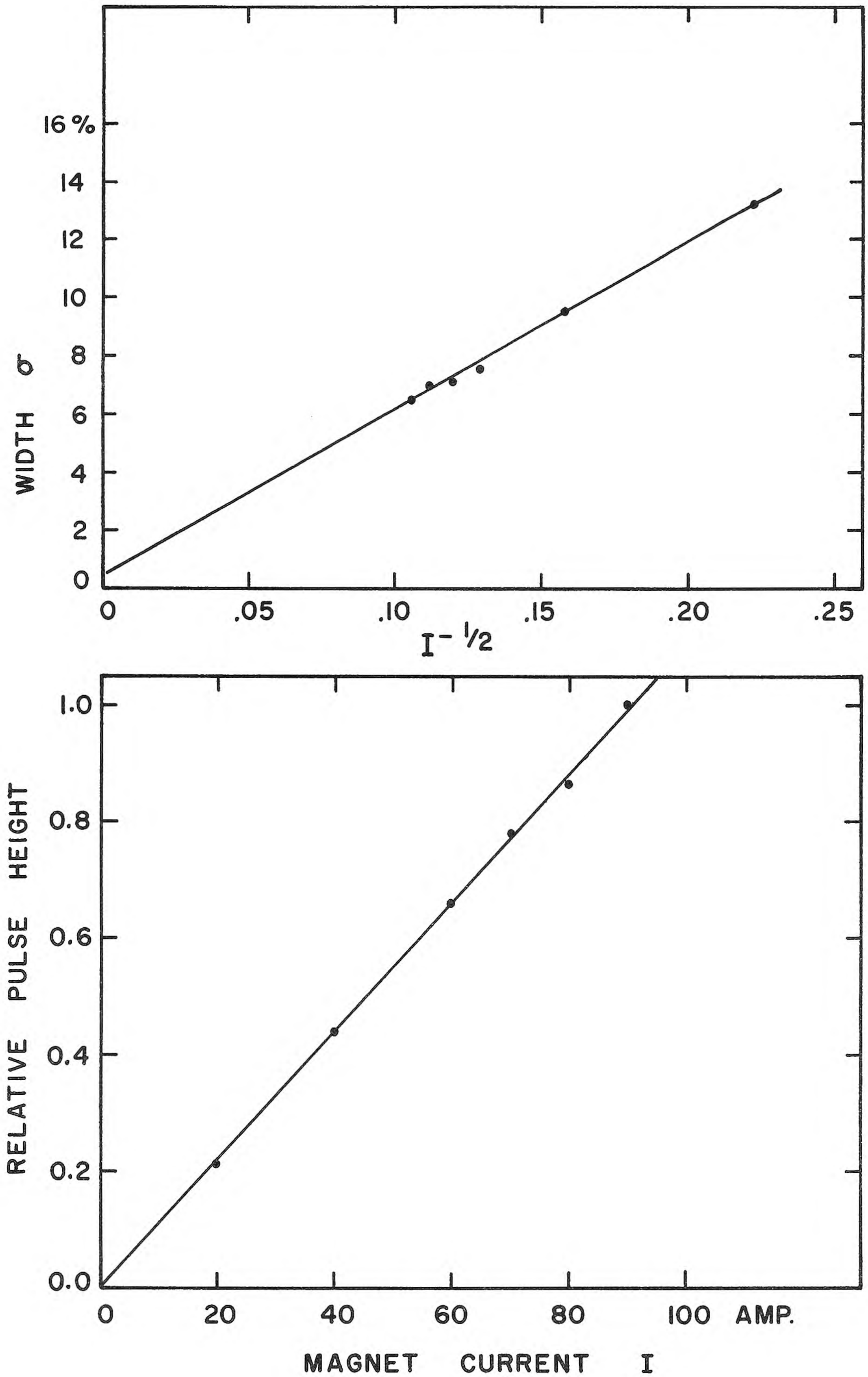


FIGURE 4: Linearity and width of the Cerenkov counter response.

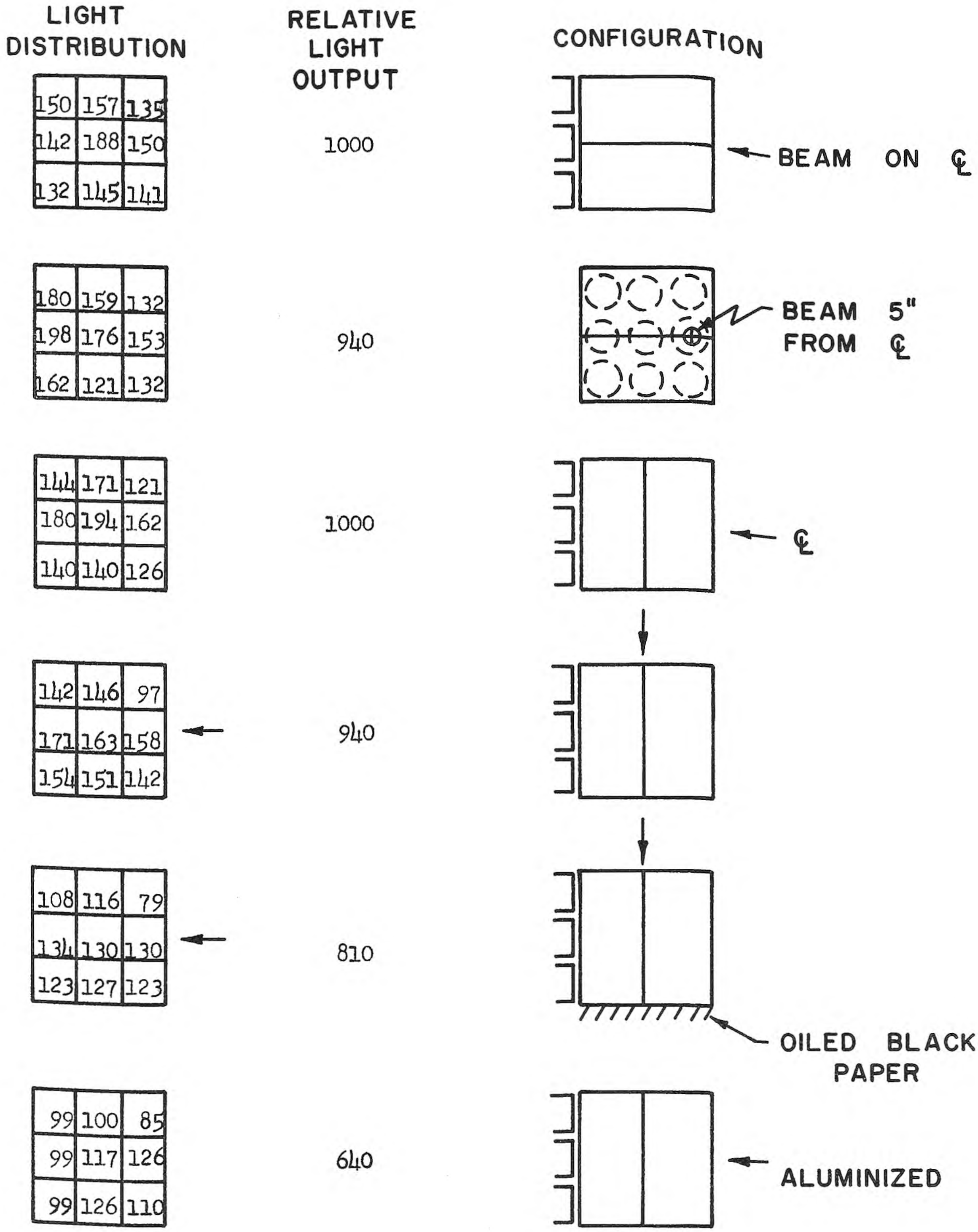


FIGURE 5: Distribution of light over the surface of the glass blocks. The beam and phototube arrangement are shown schematically on the right. The column labelled "Relative Light Output" gives the overall comparison between configurations while the light distribution is relative within a given configuration.